| Festschrift zum 60. Geburtstag von Erik Flügel | | | | Redaktion: Baba Senowbari-Daryan & Albert Daurer |
|---|---|---|---|---|
| Abh. Geol. B.-A. | ISSN 0378-0864 ISBN 3-900312-90-7 | Band **50** | S. 369–379 | Wien, 6. April 1994 |

# Origin and Transport Mechanisms of Non-Carbonate Sediments in a Carbonate-Dominated Environment (Northern Safaga Bay, Red Sea, Egypt)

By WERNER E. PILLER & ABBAS M. MANSOUR*)

With 6 Text-Figures, 3 Tables and 1 Plate

*Ägypten*
*Rotes Meer*
*Sedimentologie*
*Siliziklastika*
*Karbonat*

## Contents



## Herkunft und Transport nichtkarbonatischer Sedimente in einer karbonat-dominierten Umgebung (Nördliche Bucht von Safaga, Rotes Meer, Ägypten)

### Zusammenfassung

In der Nördlichen Bucht von Safaga wurde die Verteilung und Zusammensetzung von siliziklastischem Material an 147 Proben erfaßt, und an 26 Proben wurden die Oberflächenmerkmale von Quarzkörnern untersucht. Die daraus resultierenden Daten wurden mit verschiedenen statistischen Methoden bearbeitet. Das Verteilungsmuster des Terrigenmateriales im „Südwestkanal", sowie die angularen Quarzkörner mit hohem Relief, V-förmigen Gruben und stufenförmigen Strukturen deuten auf einen fluviatilen Transport in Wadis während periodischer Regenfälle hin. Das siliziklastische Material westlich von Gazirat Safaga ist auf Erosion unterlagernder Gesteine zurückzuführen, ein Teil der Terrigensedimente in der übrigen Bucht möglicherweise ebenfalls. Manche Oberflächenstrukturen der Quarzkörner (z.B. gute Rundung, häufige Silikatfällungen) im Norden und Westen der Bucht sowie die bevorzugte nördliche Windrichtung deuten auf einen äolischen Transport der Quarze in diesen Bereichen hin. In Verbindung mit Untersuchungen an den Karbonatkomponenten konnten die Sedimente im Ostteil, die aus tieferem Wasser stammen, als Reliktsedimente erkannt werden, die ursprünglich in sehr flachem Wasser abgelagert wurden.

### Abstract

The distribution and composition of siliciclastic material of 147 samples as well as quartz grain surface features of 26 samples of the Northern Bay of Safaga were investigated with the support of several statistical methods. The tongue-like distributional pattern of the siliciclastic sediments and the presence of angular, high relief grains, v-shaped pits and steps clearly points to a fluvial origin for the material of the "Southwest channel". The material west of Gazirat Safaga and, perhaps partly, of coastal as well as deeper water occurrences in other areas of the bay is provided by erosion of underlying rocks. The coastal material in the "West" and "East" can be attributed to aeolian transport as indicated by some quartz grain surface features (e.g., good roundness, silica precipitations). A clear distinction, however, between these two modes of origin (erosional vs. aeolian) is difficult due to the complex history of these grains. The siliciclastic material in the "East area" can be attributed to relict sediments based on comparative studies of carbonate grains.

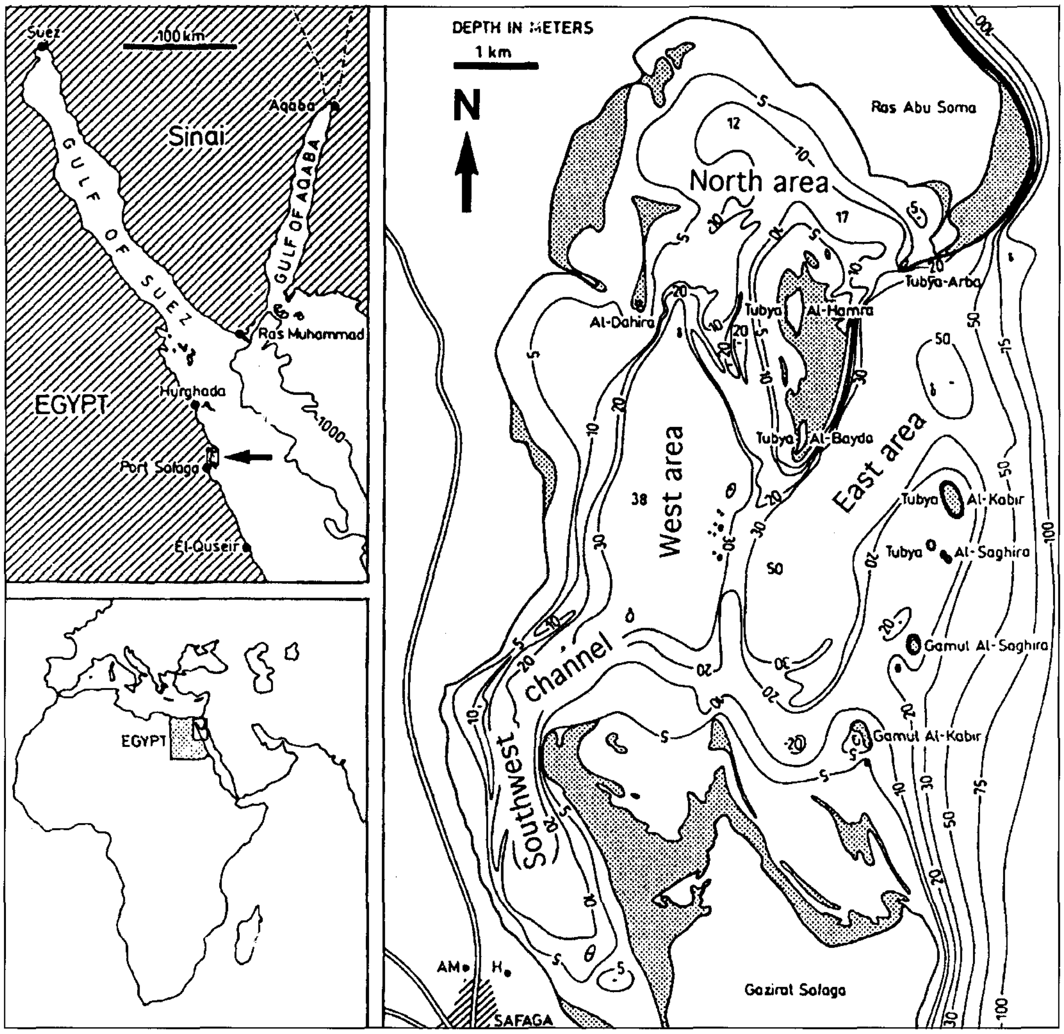
*) Anschriften der Verfasser: Dr. WERNER E. PILLER, Institut für Paläontologie, Universität Wien, Universitätsstr. 7/2, A-1010, Vienna, Austria; Dr. ABBAS M. MANSOUR, Department of Geology, Qena Faculty of Science (University of Assiut), Qena, Egypt.

## 1. Introduction

Mixed carbonate/siliciclastic environments are the exception compared with the occurrence of pure carbonate or siliciclastic sediments. However, during the last decade more and more mixed examples were described (e.g., DOYLE & ROBERTS, 1988) and the origin of siliciclastic material has been discussed (MOUNT, 1984). One region of siliciclastic influenced carbonates is represented by some parts of the Red Sea, especially in its northernmost extension, including the Gulfs of Suez and Aqaba (FRIEDMAN, 1988; ROBERTS & MURRAY, 1988). Another example in the northern part of the Red Sea is represented by the Northern Bay of Safaga (PILLER & PERVESLER, 1989; Text-Fig. 1). The sediments of this bay were described by PILLER & MANSOUR (1990) and their mixed character was clearly demonstrated. A more detailed investigation dealing with non-carbonate distribution, surface features of quartz grains and several special sediment characteristics is carried out with respect to the origin and transport mechanisms of the siliciclastic material.

## 2. Methods

The carbonate content for 147 samples (Text-Fig. 2), for the total as well as for the mud fraction alone, was detected using $CO_2$-gasometry (PILLER & MANSOUR, 1990, p. 44f.). X-ray powder diffraction analysis was also carried out for 147 bulk samples and for the mud fraction of 139 samples to determine the mineral composition of the sediments. Only 6 minerals could be detected: 3 carbonate minerals (aragonite, Mg-calcite, calcite) and 3 non-carbonate minerals (quartz, plagioclase, alkali-feldspar). The values of the x-ray diffractometry were used to calculate the mineral percentages on the base of the carbonate/non-carbonate ratio detected by $CO_2$-gasometry. The detailed procedure as well as a complete data documentation is presented in PILLER & MANSOUR (1990, p. 44f. and Appendix 4).




Text-Fig. 1.
Location map and general topography of study area.
After PILLER & MANSOUR (1990).

As surface features are found to be a helpful tool in reconstructing origin and transport mechanisms of quartz grains (e.g., KRINSLEY & DONAHUE, 1968; KRINSLEY & MARGOLIS, 1969; MARGOLIS & KRINSLEY, 1971, 1974), we also applied this method to 26 samples. The samples were selected on the base of quartz frequency in the coarse sand fraction. Although there is no unanimous opinion as to the best grain size fraction for these investigations (e.g., MARGOLIS, 1968; KRINSLEY, 1972; WILLIAMS & MORGAN, 1993), the sand fraction 500–750 $\mu$m was chosen following INGERSOLL (1974). Out of this fraction, 50 quartz grains were selected by the aid of a binocular microscope which were subsequently boiled in 30 % HCL for 10 minutes (KRINSLEY & DOORNKAMP, 1973). Out of these, 15 grains were randomly selected, mounted, gold coated, and analysed using the JEOL JSM-6400 SEM of the Institute of Palaeontology, University of Vienna. Additionally, the integrated EDS-system was used to clearify the composition of some mineral coatings on the grains.

Out of a high number of surface features reported and used by several authors (e.g., 40 features of WILLIAMS & MORGAN, 1993), 11 features were selected for the studied material which could be consistently identified by both authors (Tab. 1). A purely descriptive usage of the features was applied without any a priori genetic differentiation, e.g., in mechanical or chemical features. Their abundance was recorded by visual estimation on a rank scale. All variables (features) range between 0 (absent) and 3 (abundant) with the exception of "outline", ranging between 1

Table 1.
**Mean values of 11 quartz grain surface features of the 26 samples studied.**

| sample # | outline | relief | conchoidal fractures | straight steps | curved steps | blocky breakage p. | meandering ridges | scratches | v-shaped pits | cracks | silica precipitations |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A2 | 3,53 | 1,60 | 1,27 | 1,00 | 1,00 | 1,00 | 1,00 | 1,25 | 1,54 | 1,00 | 1,38 |
| A6 | 2,67 | 1,00 | 1,40 | 1,22 | 1,00 | 1,00 | 0,00 | 0,00 | 1,29 | 1,92 | 1,00 |
| A7 | 1,90 | 1,60 | 2,13 | 1,50 | 1,46 | 1,32 | 0,00 | 1,00 | 1,00 | 1,17 | 1,00 |
| A9 | 3,77 | 1,40 | 1,00 | 0,75 | 0,86 | 1,30 | 0,50 | 2,00 | 1,71 | 1,21 | 0,50 |
| A10 | 4,00 | 1,96 | 1,08 | 1,00 | 1,28 | 1,08 | 0,00 | 0,00 | 1,07 | 1,42 | 0,37 |
| A11 | 3,54 | 1,50 | 1,20 | 0,50 | 0,93 | 1,38 | 0,00 | 0,00 | 1,11 | 1,36 | 0,40 |
| A19 | 3,60 | 1,37 | 1,77 | 1,00 | 1,27 | 1,21 | 0,00 | 0,00 | 0,96 | 0,75 | 0,77 |
| A20 | 3,86 | 1,61 | 1,79 | 0,50 | 1,09 | 0,86 | 0,00 | 0,00 | 1,05 | 0,68 | 1,37 |
| A26 | 3,03 | 1,60 | 1,60 | 0,50 | 1,43 | 0,71 | 0,00 | 0,00 | 0,84 | 1,27 | 1,11 |
| A27 | 3,29 | 1,61 | 2,00 | 0,00 | 1,18 | 0,66 | 0,00 | 0,00 | 0,73 | 0,45 | 0,82 |
| A33 | 3,87 | 1,37 | 1,53 | 0,80 | 0,96 | 0,82 | 0,00 | 0,35 | 0,68 | 1,00 | 0,75 |
| B4 | 2,22 | 1,21 | 1,50 | 0,00 | 0,56 | 1,45 | 0,00 | 0,00 | 0,74 | 0,87 | 2,22 |
| B6 | 1,89 | 1,14 | 0,90 | 0,00 | 0,71 | 1,34 | 0,00 | 0,00 | 1,26 | 1,82 | 1,59 |
| B8 | 2,90 | 1,30 | 1,14 | 0,00 | 0,51 | 1,00 | 0,00 | 0,30 | 1,36 | 1,80 | 1,85 |
| B28 | 2,50 | 1,25 | 0,98 | 0,00 | 0,73 | 1,48 | 0,00 | 0,00 | 0,76 | 1,57 | 2,43 |
| B48 | 2,46 | 1,43 | 1,44 | 1,50 | 1,25 | 0,98 | 0,00 | 0,00 | 0,78 | 0,86 | 2,86 |
| B74 | 2,17 | 1,63 | 1,25 | 1,00 | 0,50 | 1,47 | 0,00 | 0,00 | 1,73 | 0,75 | 2,77 |
| C5 | 2,10 | 1,30 | 1,21 | 0,50 | 0,71 | 1,35 | 0,00 | 0,00 | 1,00 | 1,07 | 2,97 |
| C6 | 2,21 | 1,18 | 1,39 | 0,00 | 0,85 | 1,43 | 0,00 | 0,00 | 0,37 | 0,45 | 2,64 |
| C9 | 1,71 | 1,11 | 1,71 | 0,00 | 0,79 | 0,67 | 1,00 | 0,00 | 0,50 | 1,00 | 2,04 |
| C13 | 1,61 | 1,11 | 2,02 | 0,00 | 0,93 | 1,31 | 0,50 | 0,00 | 0,30 | 0,50 | 1,71 |
| C16 | 3,00 | 1,47 | 1,90 | 0,30 | 0,96 | 1,45 | 0,00 | 0,00 | 0,40 | 0,55 | 0,77 |
| C21 | 2,09 | 1,22 | 1,60 | 0,00 | 0,85 | 1,57 | 0,00 | 0,00 | 0,40 | 0,43 | 1,06 |
| C26 | 2,80 | 1,43 | 1,83 | 0,00 | 0,83 | 1,11 | 0,00 | 0,00 | 0,77 | 1,03 | 1,58 |
| C32 | 2,25 | 1,39 | 1,43 | 0,00 | 0,50 | 1,23 | 0,00 | 0,00 | 0,88 | 0,92 | 2,78 |
| D1 | 2,64 | 1,46 | 1,06 | 0,00 | 0,41 | 1,75 | 0,00 | 0,00 | 1,17 | 0,67 | 2,02 |

(well rounded) and 6 (very angular). Out of these data the mean was computed for each sample. These means were used in several statistical analyses: correlation analysis (Pearson correlation coefficient), cluster analyses (UPGMA using WARD method), and factor analyses (principal component analysis and Varimax rotation).

In addition to non-carbonate content and quartz grain surface features, all informations based on grain size and grain compositional analyses (PILLER & MANSOUR, 1990) as well as on microfacies analyses (PILLER, in press) were integrated in the final conclusions of this study.

## 3. Distribution of Non-Carbonate Material

The distribution of non-carbonate material shows a strong zonal pattern with highest percentages along the coast and a rapid decrease in a seaward direction.

The values show a wide range between 96 % and 2 %. The main area of the bay contains less than 10 %, only the basins in the "East" and "West area" as well as the "Southwest channel" exceeds 20 %.

Although the general distribution is well documented in Fig. 31 of PILLER & MANSOUR (1990) the pattern is much more instructive using a critical value of 30 % of non-carbonates (Text-Fig. 2).

The concentration along the main coast and along the western coast of Safaga Island is obvious; in addition, only two small isolated occurrences are present in the northeast.

The distribution along the main coast shows an interesting pattern as three tongues of higher amounts of non-carbonates occur running in a northeastern direction away from the coast.

Very high values (>60 %) are present in the mangrove channel and the intertidal area west of Safaga Island.

Table 2.
**Correlation matrix of the 11 quartz grain surface features. Bold type: 1 % significance level, italic type: 5 % significance level.**

| | outline | relief | conchoidal f. | straight steps | curved steps | blocky break. p. | meandering r. | scratches | v-shaped pits | cracks | silica precip. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| outline | **1,0000** | **0,5823** | -0,1189 | 0,3096 | 0,3628 | -0,3481 | -0,0616 | 0,2901 | 0,3292 | 0,0884 | **-0,6423** |
| relief | **0,5823** | **1,0000** | 0,0388 | *0,3926* | *0,4099* | -0,1731 | -0,1382 | 0,1687 | 0,3158 | -0,1225 | -0,3227 |
| conchoidal fractures | -0,1189 | 0,0388 | **1,0000** | 0,0388 | *0,4886* | -0,3189 | 0,0351 | -0,1392 | **-0,5665** | **-0,5437** | -0,2113 |
| straight steps | 0,3096 | *0,3926* | 0,0388 | **1,0000** | **0,5840** | -0,1885 | -0,0047 | 0,3608 | *0,4260* | 0,1891 | -0,2336 |
| curved steps | 0,3628 | *0,4099* | *0,4886* | **0,5840** | **1,0000** | *-0,4881* | -0,0152 | 0,1374 | -0,1690 | -0,0304 | **-0,5500** |
| blocky breakage pattern | -0,3481 | -0,1731 | -0,3189 | -0,1885 | *-0,4881* | **1,0000** | -0,2765 | -0,0204 | 0,0305 | -0,1538 | 0,2349 |
| meandering ridges | -0,0616 | -0,1382 | 0,0351 | -0,0047 | -0,0152 | -0,2765 | **1,0000** | *0,4745* | 0,0796 | -0,0645 | -0,0294 |
| scratches | 0,2901 | 0,1687 | -0,1392 | 0,3608 | 0,1374 | -0,0204 | *0,4745* | **1,0000** | **0,5034** | 0,1397 | -0,3145 |
| v-shaped pits | 0,3292 | 0,3158 | **-0,5665** | *0,4260* | -0,1690 | 0,0305 | 0,0796 | **0,5034** | **1,0000** | **0,4976** | -0,0805 |
| cracks | 0,0884 | -0,1225 | **-0,5437** | 0,1891 | -0,0304 | -0,1538 | -0,0645 | 0,1397 | **0,4976** | **1,0000** | -0,1350 |
| silica precipitations | **-0,6423** | -0,3227 | -0,2113 | -0,2336 | **-0,5500** | 0,2349 | -0,0294 | -0,3145 | -0,0805 | -0,1350 | **1,0000** |

Text-Fig. 2.
Sample locations and distribution of non-carbonate material >30 %.


## 4. Surface Features of Quartz Grains

For studying surface features of quartz grains not only coastal samples were selected, but also several samples with higher quartz content in the sand fraction of deeper water of the "East area". The mean values of each sample are documented in Table 1. Out of the 11 features, meandering ridges and scratches are extremely rare and straight steps are also quantitatively unimportant. No consistent pattern can be detected upon consideration of the distribution of every single feature.

A correlation analysis (Tab. 2) brought forth a strong positive correlation between outline and relief, reflecting the fact that stronger angularity is combined with higher relief. Curved and straight steps as well as v-shaped pits and cracks are highly positively correlated. V-shaped pits are also highly correlated with scratches, however, the latter are very rare. High negative correlations are present between conchoidal fractures and v-shaped pits and cracks. No positive correlations were detected for silica precipitations, strong negative ones are present with outline (high angularity) and curved steps.

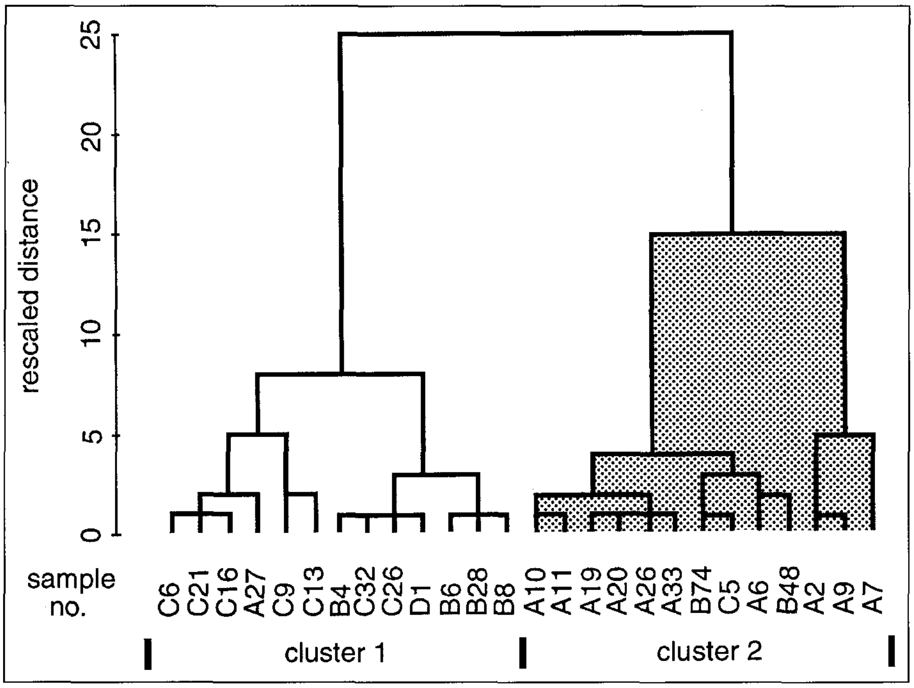
Applying a cluster analysis, a differentiation into 2 clearly distinct clusters is possible (Text-Fig. 3). For this cluster analysis only 10 features were used, as silica precipitations have been excluded due to their diagenetic nature.

Cluster 1 (Plate 1: Figs. 1–3) is characterized by better rounded grains and low relief, slightly more abundant conchoidal fractures and blocky breakage pattern, rare steps and v-shaped pits as well as less abundant cracks. Cluster 2 (Plate 1: Figs. 4–6) is differentiated by angular grains with high relief and by abundant steps and v-shaped pits (Text-Fig. 4, Tab. 3). Although not included

Table 3.
Some statistical parameters (mean value, standard deviation, minimum, maximum) of the quartz grain surface features of the 2 clusters computed by an UPGMA cluster analysis using WARD method (compare also Text-Fig. 3 and 4).

| | outline | relief | conchoidal f. | straight steps | curved steps | blocky break. p. | meandering r. | scratches | v-shaped pits | cracks | silica precip. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **cluster 1** | | | | | | | | | | | |
| mean | 2,393 | 1,298 | 1,498 | 0,023 | 0,755 | 1,265 | 0,115 | 0,023 | 0,741 | 0,928 | 1,809 |
| st. dev. | 0,5144 | 0,1599 | 0,3892 | 0,0832 | 0,2174 | 0,3291 | 0,2996 | 0,0832 | 0,3515 | 0,5074 | 0,6472 |
| minimum | 1,61 | 1,11 | 0,90 | 0,00 | 0,41 | 0,66 | 0,00 | 0,00 | 0,30 | 0,43 | 0,77 |
| maximum | 3,29 | 1,61 | 2,02 | 0,30 | 1,18 | 1,75 | 1,00 | 0,30 | 1,36 | 1,82 | 2,78 |
| | | | | | | | | | | | |
| **cluster 2** | | | | | | | | | | | |
| mean | 3,115 | 1,490 | 1,436 | 0,906 | 1,057 | 1,114 | 0,115 | 0,354 | 1,136 | 1,112 | 1,326 |
| st. dev. | 0,7610 | 0,2257 | 0,3222 | 0,3578 | 0,2789 | 0,2416 | 0,2996 | 0,6492 | 0,3398 | 0,3401 | 0,9347 |
| minimum | 1,90 | 1,00 | 1,00 | 0,50 | 0,50 | 0,71 | 0,00 | 0,00 | 0,68 | 0,68 | 0,37 |
| maximum | 4,00 | 1,96 | 2,13 | 1,50 | 1,46 | 1,47 | 1,00 | 2,00 | 1,73 | 1,92 | 2,97 |

Text-Fig. 3.
Dendrogram of a cluster analysis (UPGMA using WARD method) including 10 quartz grain surface features (silica precipitations excluded) exhibiting 2 clearly distinct clusters.



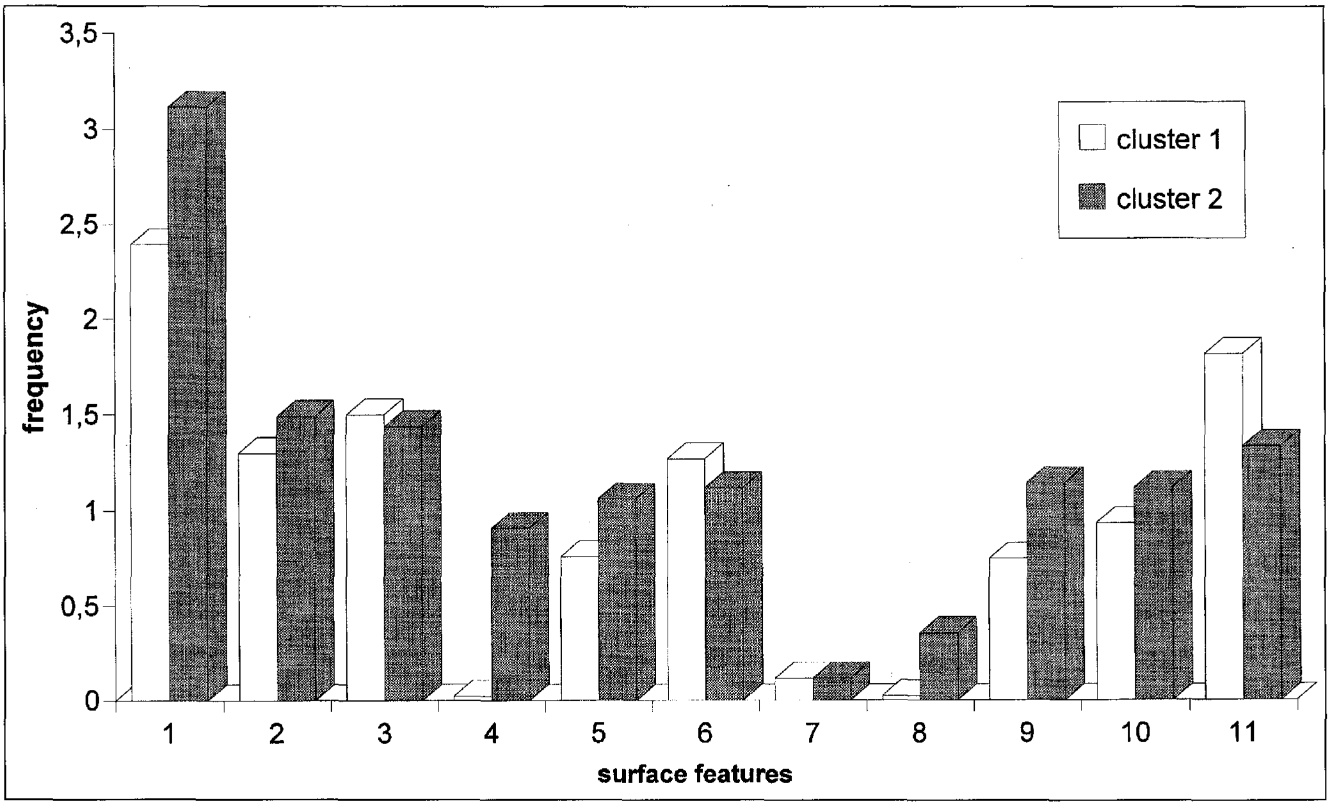

in the analysis, silica precipitations are much more abundant in cluster 1.

The sample distribution related to the 2 clusters represents generally a clear pattern as samples of cluster 1 are restricted to the northern part of the bay and samples of cluster 2 to the "Southwest channel". However, sample A 27 of cluster 1 and samples B 48, B 74 and C 5 of cluster 2 do not fit into this pattern (Text-Fig. 5).

The distribution of silica precipitations (Plate 1: Figs. 7–8) on quartz grains (Text-Fig. 6) clearly shows higher abundant occurrence in the samples of the "East area". However, some samples on the main coast (D 1, C 9 and C 6) and the sample from the intertidal area between Tubya Al-Bayda and Tubya Al-Hamra (B 74) also have abundant silica precipitations.

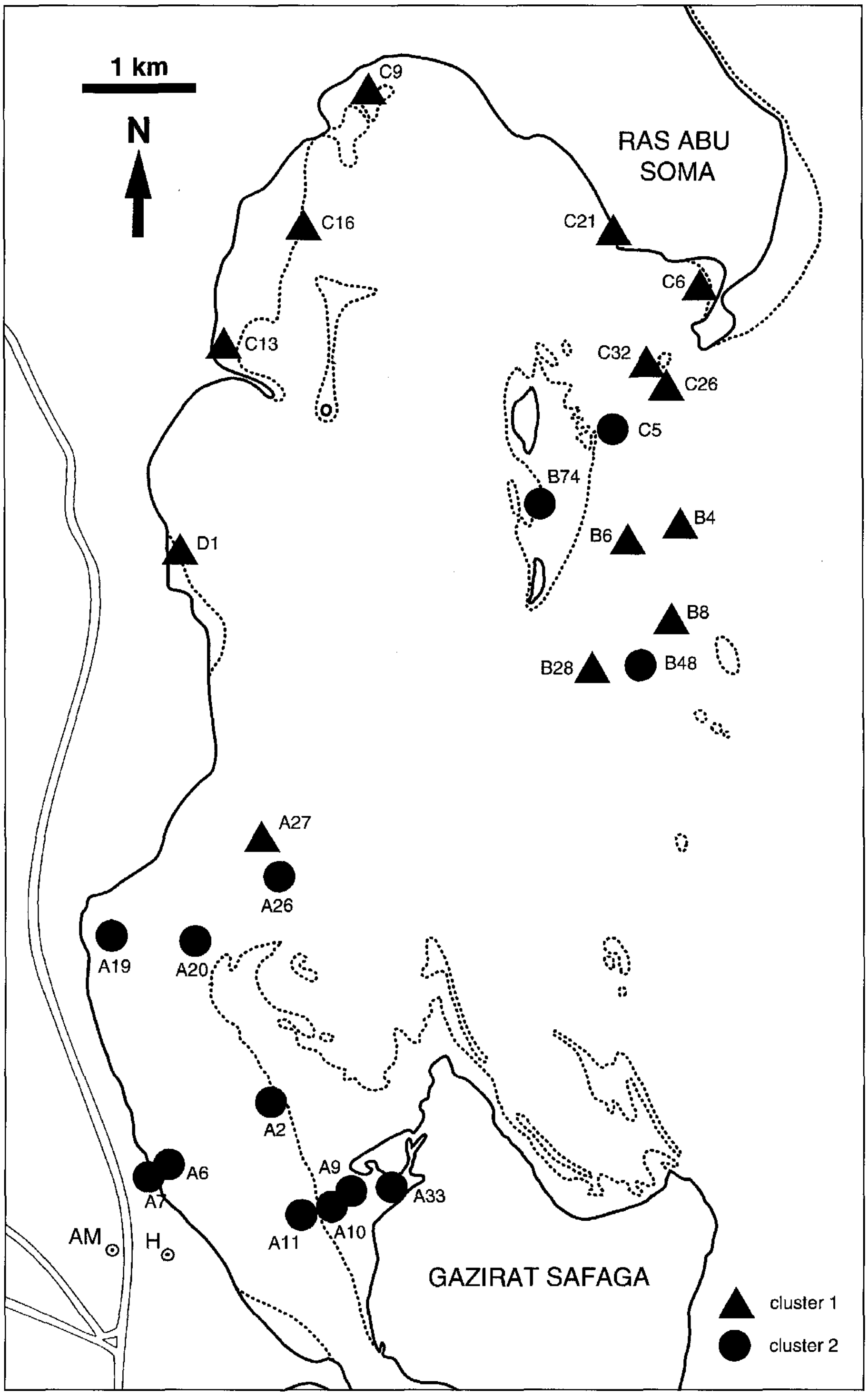
## 5. Discussion

The distributional pattern of the non-carbonate content, with high percentages exclusively along the coasts, as presented in Text-Fig. 2 and in PILLER & MANSOUR (1990), clearly suggests a direct land derivation of the majority of this material. This pattern, however, also implies different modes of input: except for two small areas in the northeast (samples C 7, C 26, C 31, C 32), higher contents are restricted to a very narrow strip in the "West" and "North area", covering the rocky intertidal flats and only up to a few hundred meters of the shallow subtidal zone. On the contrary, in the "Southwest channel" and at its northern margin not only a narrow strip occurs, but also tongues of




Text-Fig. 4.
Frequency of 11 quartz grain surface features (mean values) in the 2 clusters computed by an UPGMA cluster analysis using WARD method. See Tab. 1 for allocation of the surface features.

Text-Fig. 5.
Distribution of samples related to the 2 clusters basing on a cluster analysis (UPGMA, Ward method) using 10 quartz grain surface features.

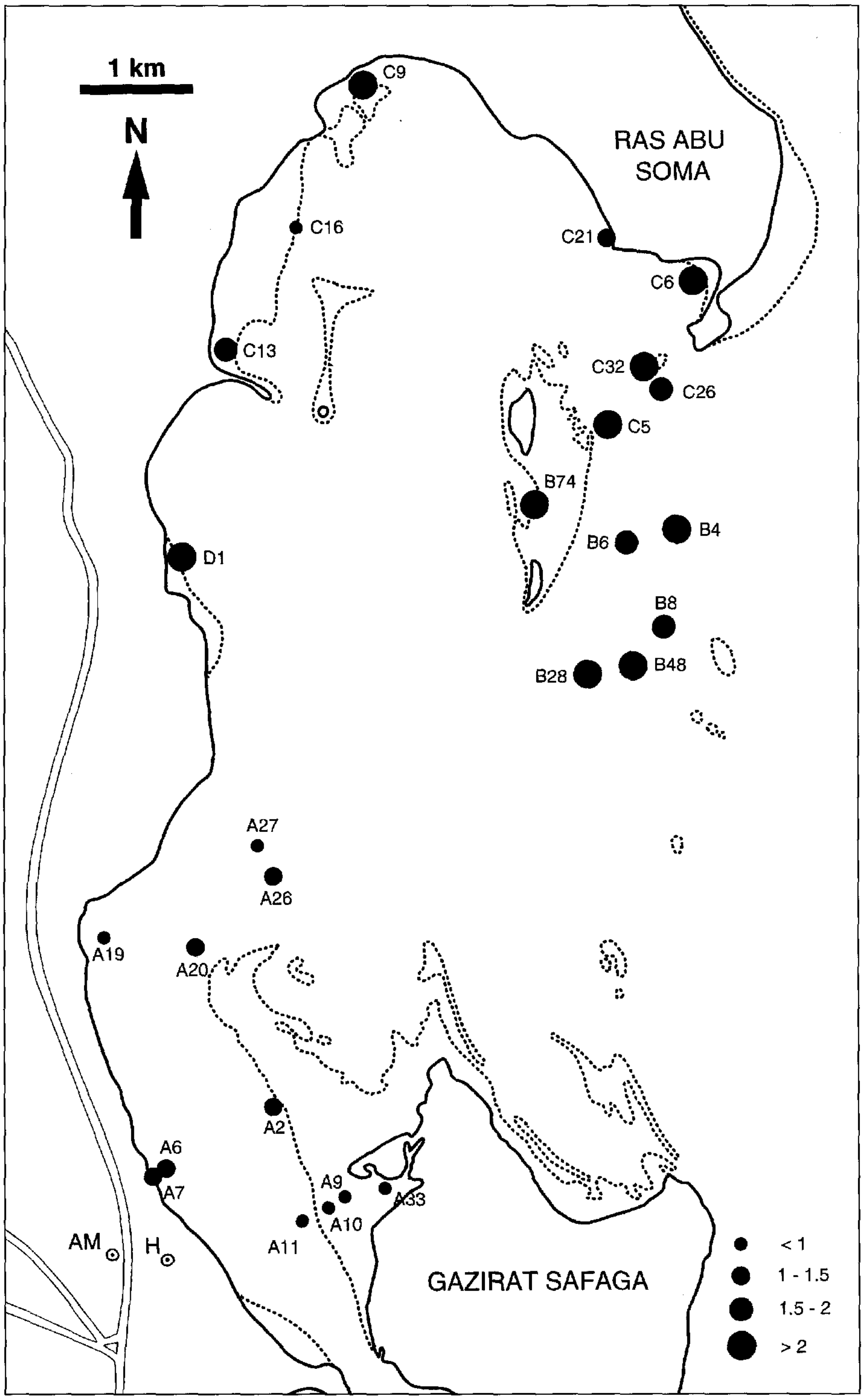



higher siliciclastic contents are developed which can be traced in a seaward direction for more than 2 km (Text-Fig. 2). The orientation of these tongues is strictly to the northeast. Additionally, the mangrove channel and the intertidal flat off Gazirat Safaga also exhibit high non-carbonate contents. Comparing this pattern with that of the quartz grain surface features as reflected in the distribution of the 2 clusters (Text-Fig. 5) a general coincidence is observable as most samples of cluster 2 are located in the "Southwest channel". The characteristic features of this cluster are angular grains with high relief and abundant steps and v-shaped pits. These features reflect strong mechanical actions as they are produced by fluvial transport or littoral agitation (e.g., CATER, 1984; FRIHY & STANLEY, 1987). This possible interpretation fits well in the general pattern, as wadis are present just in that area where siliciclastic tongues originating from the west coast of the "Southwest channel" occur. However, the occurrence of high non-carbonate contents and quartz grain surface features of cluster 2 in the mangrove channel and the intertidal flat off Gazirat Safaga cannot be explained by modern fluvial transport through wadis. Although no observations are available from this island, its dimensions do not seem to be large enough to produce a wadi of this potential especially as the occurrence of these sediments is so close to its northern tip. More probably, these siliciclastic sediments are a product of the erosion of underlying rocks. These rocks can be impure carbonate rocks of Pleistocene age as present all around the bay or they can also be part of the crystalline basement. This liberated sediment may be distributed by tidal currents out of the mangrove channel and on the tidal flat.

The confinement of higher contents of non-carbonate material to a narrow strip along the coast for the main part of the bay clearly points to the absence of an agent distributing sediment in a canalized, unidirectional way as reflected by the "siliciclastic tongues" in the "Southwest channel". All samples along the main coast (outside the "Southwest channel") belong to cluster 1 and are characterized by relatively better rounding, lower relief and distinctly less abundant v-shaped pits and steps. Better roundness and lower relief point to more constant movement, whereas less abundant v-shaped pits and steps to lower energy conditions. These characters may be assigned to wave movements at the beach reflecting relatively low energy conditions. The location of these samples along a sheltered, low energy coast fits well into this interpretation, however, it does not provide any explanation on the origin of the siliciclastic material. There may be two principal modes of input for this material:

1) reworking of underlying rocks
   or
2) aeolian transport.

Text-Fig. 6.
Distribution of silica precipitations on quartz grains (abundance data represent means of estimation values on a rank scale between 0 [absent] and 3 [abundant]).




Hints to a more or less autochthonous production by erosion of the underlying impure Pleistocene carbonate rocks are provided by the occurrence of rocky tidal flats. Some of the samples originate from these flats (C 13) or from their edges (D 1, C 16) and the flats represent nothing else than recent abrasion platforms of the Pleistocene rocks. On the contrary, the prevailing northerly winds (PILLER & PERVESLER, 1989) offer ideal conditions for aeolian transport into this part of the bay. Constantly decreasing contents of non-carbonate material in seaward direction do not contradict this mode of input. Taking the degree of silica precipitations on the quartz grains into consideration (Text-Fig. 6) also no consistent pattern is discernable with values ranging between 0.77 and 2.64. Consequently, from quartz grain surface features alone a distinction between these 2 modes of input is impossible.

In addition to the samples with high non-carbonate contents of cluster 1 along the coast, there are some samples with lower siliciclastic contents also classified within this cluster occurring in the "East area". The non-carbonate content of these samples ranges between 7 and 37 % and the quartz grain surface features are in the range of the coastal samples. However, the samples come from water depths between 29 and 45 m and therefore the origin of surface features cannot easily be explained by moderate wave action on the beach. Considering the results of thin section analysis (PILLER, in press) it is obvious that, at least some of these samples are characterized by the presence of multilamellar ooids (sometimes also inside lithoclasts), by strong blackening of some particles and by several corrosion features. Due to these characteres, these sediments can be interpreted as relict sediments, probably reflecting very shallow water conditions during a Pleistocene sea level lowstand. This interpretation enables the production of the quartz grain surface features in a beach environment, albeit a fossil one. No indications as to the origin of the non-carbonate particles during the Pleistocene are available.

There are 3 samples (B 48, C 5, B 74) of cluster 2 which are not located in the "Southwest channel". They show a much better roundness compared to most of the other samples of cluster 2. B 48 and C 5 originating from the "East area" occur together with those samples interpreted above as being relict and also exhibit the same features (ooids, corrosion, blackening). Sample B 74 comes from the tidal flat between the 2 Tubyas showing rare ooids but no blackening. The origin of these non-carbonate constituents may be due to abrasion of the impure Pleistocene carbonate rocks. Contrary to these 3 samples, A 27 is grouped in cluster 1, however, originates from the northeasternmost part of the "Southwest channel". In fact, some of the surface features are closer to cluster 2 (especially outline and relief) and the classification within cluster 1 being based mainly on higher abundance of conchoidal fractures and steps. A fluvial origin of these non-carbonates can still be stated, based on these characters.

One of the main characters of the studied non-carbonate sediment constituents is their complex derivational history. Even the relatively clear fluvial origin of most non-carbonates in the "Southwest channel" is obscured in some samples. The coastal sediments of samples A 6 and A 7 exhibit well rounded quartz grains not directly reflecting fluvial transport. However, together with other features and due to the general situation their fluvial supply is relatively clear.

The occurrence of abundant silica precipitations is restricted to samples outside the "Southwest channel". All samples of the "Southwest channel" have values $<1.5$, only one sample outside the channel has also a value $<1.5$ (C 16). This distribution reinforces the interpretation of fluvial transport (W coast) and erosional liberation out of underlying rocks (W' of Gazirat Safaga) for the siliciclastic material of these samples. This suggests on the one hand that the material is neither imported with silica precipitations nor that the liberated particles were coated prior to liberation. On the other hand, there was not enough stability and/or time to produce silica precipitations out of the sea water. This is in contrast to the other samples: for those interpreted as relict sediments the heavy coating with silica precipitations can easily be explained with the time available and with the quiet water conditions in the deeper water environment. For the coastal samples this could be explained by imported silica precipitations or by precipitations produced recently in this shallow water environment. Due to present, although moderate sediment agitation, a recent formation of these precipitations seems less probable. More probable is either an aeolian transport of silica coated quartz grains or that the liberated grains out of the underlying Pleistocene carbonates had coatings prior to their liberations. The first possibility of aeolian transport seems to be more likely.

Taking into consideration the documented complex history of the quartz grains, it is difficult to assign the origin of the siliciclastic material to one of the main categories as proposed by MOUNT (1984). For the Gulf of Aqaba FRIEDMAN (1968, 1988) takes 3 categories into consideration: punctuated mixing, in situ mixing, source mixing. PILLER & MANSOUR (1990, p. 87) postulated "punctuated mixing", facies mixing and source mixing as dominating processes for the Northern Bay of Safaga.

On the basis of the new investigations "punctuated mixing" can be confirmed as the most important mechanism of siliciclastic supply in the "Southwest channel". Here the input takes place by periodic fluvial transport during flashfloods ending in relatively sharply bordered, nearly unidimensional distributions. The second, very frequently occurring process of mixing is "source mixing". It is represented by the erosion of uplifted Pleistocene mixed carbonate/siliciclastic rocks. This erosion creates on the one hand large areas of rocky tidal flats and provides, on the other hand, siliciclastic material for the mixing process. In addition to the siliciclastic material low Mg-calcite may also be provided by this erosion (PILLER & MANSOUR, 1990). Source mixing is thought to be important on the west coast of Gazirat Safaga and perhaps also along the main coast in the "West" and "North area" due to coastal erosion. Another kind of "source mixing" is represented by the relict sediments of the "East area" occurring in slightly deeper water. These sediments may represent a mixture of Pleistocene or subrecent mixed carbonate/siliciclastic sediments with a certain amount of recent carbonate. Whereas the relict sediment is built by skeletal as well as non-skeletal carbonate particles (e.g., ooids, pellets, lithoclasts), the modern sediment supply is dominated by skeletal material. For some areas "facies mixing" seems to be more common. This mode was favored by PILLER & MANSOUR (1990) due to direct observations of wind transported sediments. Although the quartz grain surface features do not provide clear evidence for aeolian transport, this may be suggested by the distribution of silica precipitations. In addition, due to direct observations during heavy northerly winds at least some amount of siliciclastic material must be provided by aeolian action. "In situ mixing" sensu MOUNT (1984) is of minor importance and occurs only together with "source mixing" and/or "facies mixing". It takes place in highly terrigenous coastal sediments (originating by "source mixing") when autochthonous shell material (e.g., molluscs, larger foraminifera, etc.) is added.

## 6. Conclusions

The distribution of non-carbonate sediment constituents and quartz grain surface features point to three different modes of input of terrigenous material into the Northern Bay of Safaga:

❶ The majority of siliciclastic material in the "Southwest channel" is delivered by fluvial transport during flashfloods. This material is canalized in wadis and also unidirectionally distributed into the marine environment. This mode of supply represents "punctuated mixing".

❷ The siliciclastic materials on the west coast of Gazirat Safaga and, at least partly, along the main coast of the "West" and "North area" originate from erosion of impure carbonate rocks of Pleistocene age. This mode of supply can be assigned to "source mixing". A special case of source mixing is represented in the deeper water samples of the "East area", where relict (Pleistocene to subrecent) sediments of mixed carbonate/siliciclastic composition are present.

❸ Parts of the terrigenous material along the main coast of the "West" and "North area" can be attributed to aeolian transport by the prevailing northerly winds representing the category of "facies mixing".

Considering only quartz grain surface features, a clear distinction of the different modes of supply is not possible. The main reason for this is the complex history of the quartz grains including several cycles with different modes of transport and incorporation into different environments. However, the combination of several methods, also including carbonate sediment analyses, allow for a better understanding of these complex interactions and provide, at least partially, a viable explanation.

#### Acknowledgements

The present work was carried out within the framework of projects P 5877 and P 7507-GEO of the Austrian "Fonds zur Förderung der wissenschaftlichen Forschung" (FWF). Thanks are due to all coworkers of these projects (R. GOLEBIOWSKI, K. KLEEMANN, J.H. NEBELSICK, P. PERVESLER, C. RUPP, F.F. STEININGER), to the entire staff of the Austrian Cultural Institute in Cairo, and to the Geological Department of the University of Assiut/Qena. Thanks are also due to E. LIBOWITZKY for help with the EDS-system and to J.H. NEBELSICK for help with the English. The photographs were printed by R. GOLD and some graphical help was povided by N. FROTZLER.

## References


CATER, J.M.L. (1984): An application of scanning electron microscopy of quartz sand surface textures to the environmental diagnosis of Neogene carbonate sediments, Finestrat Basin, south-east Spain. – Sedimentology, **31**, 717–731, 24 Fig., Oxford.

DOYLE, L.J. & ROBERTS, H.H. (eds.) (1988): Carbonate-Clastic Transitions. – Developments in Sedimentology, **42**, 304 pp.; Amsterdam.

FRIEDMAN, G.M. (1968): Geology and Geochemistry of Reefs, Carbonate Sediments, and Waters, Gulf of Aqaba (Elat), Red Sea. – J. Sedimentary Petrology, **38**, 895–919; Tulsa.

FRIEDMAN, G.M. (1988): Case Histories of Coexisting Reefs and Terrigenous Sediments: the Gulf of Elat (Red Sea), Java Sea, and Neogene Basin of Negev, Israel. – In: Carbonate-Clastic Transitions (Ed. by DOYLE, L.J. & ROBERTS, H.H.), Developments in Sedimentology, **42**, 77–97; Amsterdam.

FRIHY, O.E. & STANLEY, D.J. (1987): Quartz grain surface textures and depositional interpretations, Nile Delta region, Egypt. – Marine Geology, **77**, 247–255, 3 Fig., Amsterdam.

INGERSOLL, R.V. (1974): Surface textures of first cycle quartz sand grains. – J. Sedimentary Petrology, **44**, 151–157; Tulsa.

KRINSLEY, D.H. (1972): Surface features of quartz sand grains from Leg 18 of the Deep Sea Drilling Project. – Initial Reports of the Deep Sea Drilling Project, **18**, 925–933; Washington, D.C.

KRINSLEY, D.H. & DONAHUE, J. (1968): Environmental interpretation of sand grain surface textures by electron microscopy. – Geol. Soc. Amer. Bull, **79**, 743–748; New York.

KRINSLEY, D.H. & DOORNKAMP, J.C. (1973): Atlas of quartz sand surface textures. – 91 pp.; Cambridge Univ. Press; London.

KRINSLEY, D.H. & MARGOLIS, S.V. (1969): A study of quartz grain surface textures with the scanning electron microscope. – Trans. N.Y. Acad. Sci., **31**, 457–477; New York.

MARGOLIS, S.V. (1968): Electron microscopy of chemical solution and mechanical abrasion features on quartz sand grains. – Sedimentary Geology, **2**, 243–256.

MARGOLIS, S.V. & KRINSLEY, D.H.. (1971): Submicroscopic frosting on eolian and subaqueous sands. – Geol. Soc. Amer. Bull., **82**, 3395–3406; New York.

MARGOLIS, S.V. & KRINSLEY, D.H. (1974): Processes of formation and environmental occurrence of microfeatures on detrital quartz grains. – Amer. Jour. Sci., **274**, 449–464.

MOUNT, F.F. (1984): Mixing of siliciclastic and carbonate sediments in shallow shelf environment. – Geology, **12**, 432–435, 1 Fig., Boulder.

PILLER, W.E. (in press): The Northern Bay of Safaga (Red Sea, Egypt): an actuopalaeontological approach. IV. Thin section analysis. – Beiträge zur Paläontologie, **18**, Wien.

PILLER, W.E. & MANSOUR, A.M. (1990): The Northern Bay of Safaga (Red Sea, Egypt): an actuopalaeontological approach. II. Sediment analyses and sedimentary facies. – Beitr. Paläont. Österreich, **16**, 1–102, 55 Fig.; Wien.

PILLER, W.E. & PERVESLER, P. (1989): The Northern Bay of Safaga (Red Sea, Egypt): an actuopalaeontological approach. I. Topography and Bottom facies. – Beitr. Paläont. Österreich, **15**, 103–147, 8 Fig., 10 Pl., 1 map; Wien.

ROBERTS, H.H. & MURRAY, S.P. (1988): Gulfs of Northern Red Sea: Depositional Settings of Distinct Siliciclastic-Carbonate Interface. – In: Carbonate-Clastic Transitions (Ed. by DOYLE, L.J. & ROBERTS, H.H.), Developments in Sedimentology, **42**, 99–142, 26 Fig., Amsterdam.

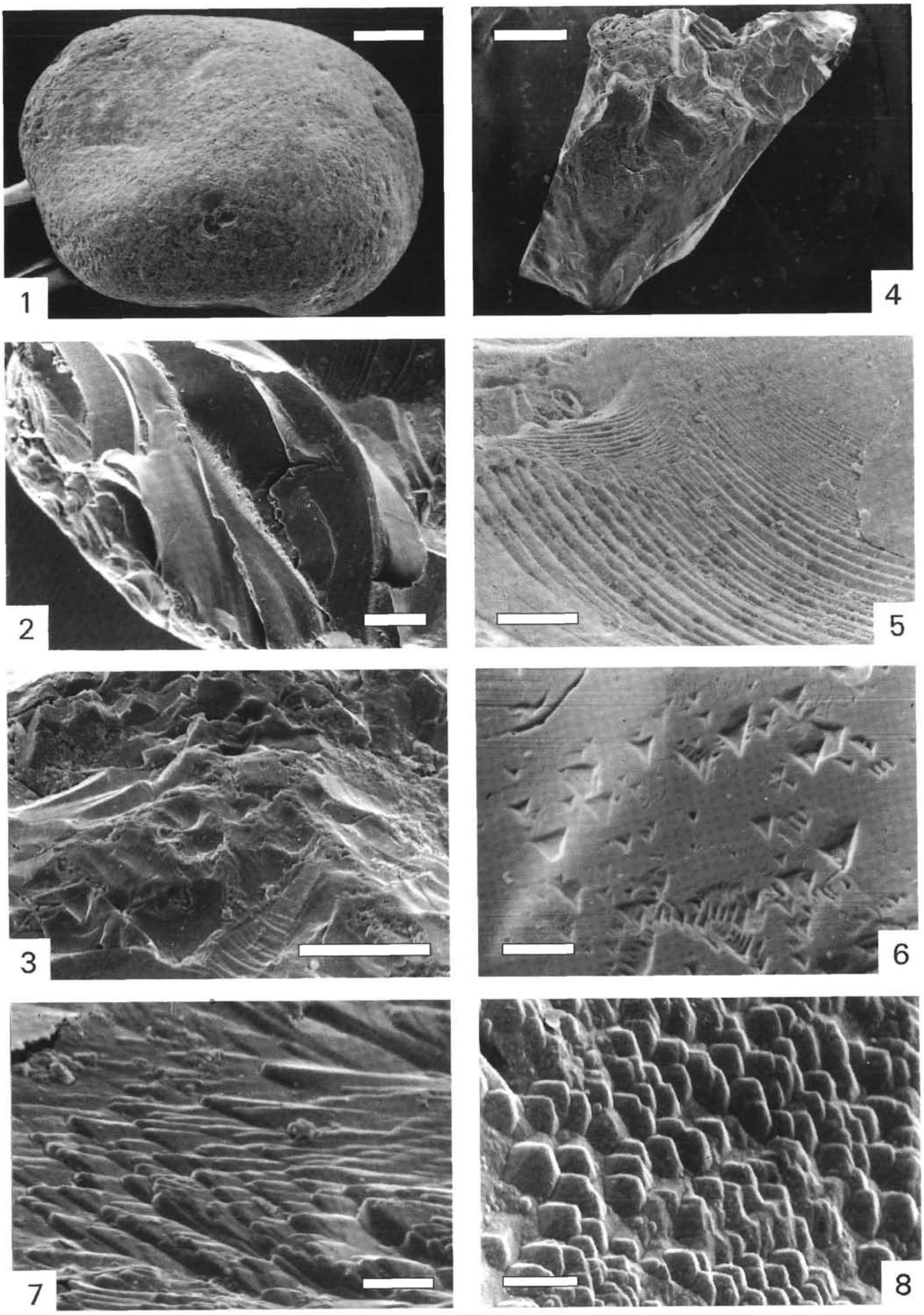
WILLIAMS, A.T. & MORGAN, P. (1993): Scanning electron microscope evidence for offshore onshore sand transport of Fire Island, New York, USA. – Sedimentology, **40**, 63–77, 20 Fig., London.

## Plate 1

Figs. 1–3: **Typical quartz grain surface features of cluster 1.**
- Fig. 1: Quartz grain with well rounded outline and low relief.
  Scale bar: 300 $\mu$m.
- Fig. 2: Conchoidal fractures.
  Scale bar: 40 $\mu$m.
- Fig. 3: Blocky breakage pattern.
  Scale bar: 10 $\mu$m.

Figs. 4–6: **Typical quartz grain surface features of cluster 2.**
- Fig. 4: Angular grain with high relief.
  Scale bar: 300 $\mu$m.
- Fig. 5: Curved steps.
  Scale bar: 20 $\mu$m.
- Fig. 6: V-shaped pits.
  Scale bar: 4 $\mu$m.

Figs. 7–8: **Two examples of silica precipitations showing different coatings.**
- Fig. 7: Scale bar: 8 $\mu$m.
- Fig. 8: Scale bar: 3 $\mu$m.


1
2
3
4
5
6
7
8